PCT/GB 2004/005930

10/500[illegible]18

The Patent Office

INVESTOR IN PEOPLE

10 Rec'd PCT/PTO 28 JUN 2004

**PRIORITY DOCUMENT**

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)


The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ


REC'D 07 FEB 20[illegible]

WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed [signature]

Dated 23 January 2003

BEST AVAILABLE COPY

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
L
14 AUG 2002
NEWPORT

The Patent Office

1/77

14AUG02 E740807-1 D02813
P01/7700 0.00-0218842.3

# Request for grant of a patent

*(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)*

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

| | | |
|---|---|---|
| 1. | Your Reference | P51078u GB |
| 2. | Patent Application number *(The Patent Office will fill in this part)* | 0218842.3 — 14 AUG 2002 |
| 3. | Full name, address and postcode of the or each applicant *(underline all surnames)* | Bookham Technology plc<br>90 Milton Park<br>Abingdon<br>Oxon<br>OX14 4RY |
| | Patents ADP Number *(if you know it)* | 7909757001 |
| | If the applicant is a corporate body, give the country/state of its incorporation | England & Wales |
| 4. | Title of the invention | A Light Sensor |
| 5. | Name of your agent *(if you have one)* | Fry Heath & Spence |
| | "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* | The Old College<br>53 High Street<br>Horley, Surrey RH6 7BN |
| | Patents ADP Number *(if you know it)* | 05880273001 |

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or each of these earlier applications and *(if you know it)* the or each application number.

| Country | Priority application number *(if you know it)* | Date of filing *(day / month / year)* |
|---|---|---|
| GB | 0131001.0 | 27 / 12 / 2001 |

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application.

| Number of earlier application | Date of filing *(day / month / year)* |
|---|---|
| | |

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*

*a) any applicant named in part 3 is not an inventor; or*

*b) there is an inventor who is not named as an applicant, or*

*c) any named applicant is a corporate body.*

*(See note (d))*

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document.

| | |
|---|---|
| Continuation sheets of this form | |
| Description | 14 |
| Claim*(s)* | 4 |
| Abstract | 0 |
| Drawing*(s)* | 3 +3 |

DM

10. If you are also filing any of the following, state how many against each item.

| | |
|---|---|
| Priority documents | |
| Translations of priority documents | |
| Statement of inventorship and right to grant of a patent *(Patents Form 7/77)* | |
| Request for preliminary examination and search *(Patents form 9/77)* | 1 |
| Request for substantive examination *(Patents form 10/77)* | |
| Any other documents *(please specify)* | |

11. I/We request the grant of a patent on the basis of this application.

Signature S. G. Unwin

Date 13 August 2002

12. Name and daytime telephone number of person to contact in the United Kingdom — S. G. Unwin, 01865 841060

**Warning**

*After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you filing or applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.*

**Notes**

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

# A LIGHT SENSOR

This invention relates to a light sensor and more particularly a light sensor that may be formed as part of an integrated optical circuit.

A variety of different types of light sensor that can be hybridised with or integrated on an integrated optical circuit are known.

The present invention provides an improved form of light sensor which provides a variety of advantages over the prior art.

According to a first aspect of the invention, there is provided a light sensor comprising: a light conductive path, a portion of said path being arranged to generate free charge carriers when light of a selected wavelength or selected range of wavelengths passes along the path; wavelength selective reflector means being arranged to reflect light of said selected wavelength or selected range of wavelengths so it passes repeatedly through said portion; and detector means arranged to detect the presence of the free charge carriers thus generated.

According to a second aspect of the invention, there is provided a series of such light sensors. Each sensor in the series may be arranged to detect light of a different wavelength or wavelength band.

According to another aspect of the invention, there is provided a photodiode comprising a p-i-n diode formed in a semiconductor substrate having an energy band gap the magnitude of which corresponds to absorption of photons of a first wavelength, the photodiode comprising a substantially intrinsic region in said semiconductor substrate between p- and n-doped regions, the intrinsic region being modified to introduce deep band gap levels therein so as to provide at least partial absorption of photons of an optical

signal of a selected wavelength or wavelength band greater than said first wavelength and thus generate an electrical signal across the p-i-n diode indicative of said optical signal, said photodiode being provided within a resonant cavity.

Preferred and optional features of the invention will be apparent from the following description and from the subsidiary claims of the specification.

The invention will now be further described, merely by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a schematic plan view of one form of photodiode (which is described further in GB0131001.0) to which the present invention can be applied;

Figure 2 is a cross-sectional view taken along line A-A' of Figure 1;

Figure 3 shows this type of diode modified according to a preferred embodiment of the invention;

Figure 4 is a perspective view of a Bragg grating as may be used in the arrangement shown in Figure 3;

Figure 5 is a schematic plan view of a known form of optical channel monitor;

Figure 6 is a schematic plan view of a series of light sensors according to the present invention arranged to monitor a plurality of wavelengths;

Figure 7 is a schematic diagram illustrating a typical known arrangement of an optical channel monitor;

Figure 8 is a schematic plan view of a serpentine version of the series shown in Figure 6; and

Figure 9 is a further embodiment of the modified diode shown in Figure 3.

The present invention builds upon a form of photodiode described in the applicant's earlier applications GB0131001.0 and GB0131003.6 the disclosures of which are incorporated herein. Figure 1 shows a plan view of the type of photodiode described in these earlier applications and Figure 2 shows a cross-section thereof.

The photodiode is formed as part of an integrated optical waveguide 1, e.g. a rib waveguide formed in silicon, preferably in a silicon-on-insulator (SOI) substrate. The photodiode is arranged to be able to detect selected wavelengths, in particular wavelengths in the range 1.5-1.6 microns as widely used in telecommunications applications. Normally, silicon is transparent at these wavelengths but a portion 1A of the waveguide 1 is modified so as to at least partially absorb wavelengths in this range leading to the generation of free charge carriers in the waveguide. There are a variety of ways of doing this as described in these earlier applications, one way being to implant impurity atoms, e.g. gold or protons, in the waveguide so as to form deep band gap levels which enable the silicon to absorb light of the selected wavelength or wavelength band.

A p-i-n diode is provided to detect the presence of the charge carriers generated in this way. In the arrangement shown, p- and n- doped regions are formed on opposite sides of the waveguide 1, which is nominally intrinsic, and the p-i-n diode thus formed is used to generate an electric signal which is indicative of the power of the light signal being sensed.

Figure 2 shows the SOI substrate comprising a silicon layer 4 separated from a supporting substrate 5 (typically also of silicon) by an optical confinement

layer 6, typically of silicon dioxide (which performs an insulating function in electrical applications – hence the terminology silicon-on-insulator). The rib waveguide 1 comprises a rib 1B upstanding from a slab region 1C both of which are formed in the silicon layer 4. The p- and n- doped regions 2, 3 are formed at the base of recesses 1D, 1E formed in the silicon layer 4 and electrical contacts 7, 8 provided thereon. A passivating oxide layer 9 is provided over the silicon layer 4, except where the electrical contact is made with the doped regions 2, 3.

Other arrangements of p-i-n diode may be used or other forms of detecting means for detecting the charge carriers generated by the absorption of light of the selected wavelength.

In the present invention, such an arrangement is modified by the provision of wavelength selective reflector means to reflect the selected wavelength or selected range of wavelengths repeatedly through the portion 1A so as to increase the absorption of the selected wavelength or selected range of wavelengths and hence the level of the signal generated.

A preferred way of achieving this is to provide a Bragg grating in the waveguide on each side of the photodiode. This is illustrated in Figure 3 which shows an input Bragg grating 11 at the input end of the waveguide 1 and an output Bragg grating 12 at the output end of the waveguide 1.

The gratings 11, 12 may be formed in the waveguide 1 using an electron beam lithography technique in a known manner. The periodicity of the gratings 11, 12 is designed such that they selectively reflect a single wavelength or a band of wavelengths. For example, in a waveguide carrying the wavelengths $\lambda_1$, $\lambda_2$, ..., $\lambda_N$, the grating may have a periodicity such that it only reflects $\lambda_2$.

Figure 4 shows a perspective view of a Bragg grating formed by etching grooves across the rib 1B of a rib waveguide.

The role of the pair of gratings 11, 12 is to tend to confine light corresponding to the grating wavelength $\lambda_n$, or wavelength range, within the region 1A of the waveguide 1 where light of that wavelength is absorbed, e.g. by the presence of gold atoms as described above. The two gratings 11, 12 together preferably form a Fabry-Perot cavity which selectively confines the wavelength $\lambda_n$ between them thus giving the detector a "resonant" condition for absorption at that wavelength. Note that because a Fabry-Perot cavity is formed then there is not a significant back-reflection of the incident light of the selected wavelength $\lambda_n$ from the input Bragg grating, i.e. input light of the selected wavelength is completely coupled into the cavity region. Light at the selected wavelength is thus forced to undergo multiple-passes of the waveguide photodetector and so, for that particular wavelength, the effective length of the photodetector is increased. The function of such a Fabry-Perot cavity is well known, e.g. as described in Chapter 9, 2nd Edition of the textbook "Optics" by Hecht published by Addison Wesley Publishing Co.

It has been found experimentally that Bragg gratings with a line length of 3.4μm and coupling coefficient, K, of $2.5cm^{-1}$ provide a good practical combination for process tolerant, high reflectivity Bragg gratings. Using these design parameters, the grating reflectivities are expected to be ~0.99 and have been shown to attenuate the selected wavelength by ~20dB in the transmission path. This implies that in a lossless waveguide the selected wavelength would effectively undergo ~500 reflections based on the theory set out in "Optics" referred to above. The implication of this is that the effective path length for the selected wavelength in the photodetector of Figure 3 is multiplied by a factor of ~500. This means that the wavelength-selective detector could be quite short in length yet have sufficient interaction with the selected wavelength, $\lambda_n$, to allow significant photoabsorption. A short length is desirable for the waveguide photodetector, not only so that the

device is compact, but also because this minimises the unwanted absorption of the wavelengths other than the selected one, $\lambda_n$.

The arrangement shown in Figure 3 can be extended to two or more such light sensors either in series in the same waveguide or in parallel in separate waveguides. Whilst some compromise in performance will have to be accepted when used in series (to allow more than one wavelength to pass through the upstream sensor or sensors whilst maintaining sufficient wavelength selectivity within each sensor), such arrangements could be useful in certain devices. One possibility is for an arrangement performing the role of an optical channel monitor (OCM). A typical, known form of OCM is shown in Figure 5 and comprises an input waveguide 20, a first free propagation region 21 leading to an arrayed waveguide grating (AWG) 22, the output of which crosses a second free propagation region 23 to a plurality of output waveguides 24 which lead to respective photodetectors 25.

Light enters the OCM device via the input waveguide 20. Typically, the input light will be made up of a spectrum of different wavelengths: $\lambda_1$, ...., $\lambda_N$. The input waveguide delivers the light into the AWG 22 which disperses the light into its component wavelengths. The light emerges from the AWG 22 onto a circle R. The point on R at which the light is focused is dependent upon its wavelength. Output waveguides 24 are provided along the circle R and these waveguides 24 transport the light to the edge of the optical chip. Each output waveguide 24 carries a different wavelength of light. The example shown has 5 waveguides but other arrangements may have fewer waveguides or more waveguides.

A photodiode array 25 is located at the edge of the chip where the output waveguides 24 terminate. Typically, this photodiode array 25 is made from a different material to the optical chip; for example, the optical chip may be a SIMOX silicon wafer while the photodiode array may be a III-V semiconductor. The photodiode array 25 must be carefully optically aligned to the output

waveguide facets and then bonded in place by a suitable epoxy; a process known as hybridisation. Each pixel of the photodiode array 25 is used to detect the light from one of the output waveguides 24 thus providing a measure of the optical power at a particular wavelength.

A plurality of light sensors can be used to provide a function similar to that of an OCM function. One way of doing this is to provide a sensor on each of the waveguides 24, each arranged to sense the wavelength received by the respective waveguide. Another way is to provide a plurality of light sensors in series as shown in Figure 6. In either case, each light sensor comprising a detection region with Bragg gratings on the input and output sides thereof, each pair of Bragg gratings being arranged reflect a different wavelength or band of wavelengths.

Figure 3 shows a series of light sensors in which light enters the series via the waveguide on the left. The light, which is composed of the wavelengths $\lambda_1$, $\lambda_2$, ..., $\lambda_N$, passes into a first wavelength-selective detector $30_1$ which has its Bragg grating pair set so as to preferentially photodetect one wavelength or a range of wavelengths. If the overall reflectivity of the grating is relatively low, the other wavelengths present in the optical signal will be largely unaffected by their passage through this first detector and will continue to propagate along the waveguide 1 to further waveguide photodetectors $30_2$,....., $30_n$. These further detectors are designed so as to selectively measure each of the remaining wavelengths or ranges of wavelengths that make up the signal so that, eventually, after a passage through N detectors (where N is the number of wavelengths in the network) every wavelength has had its power level sampled.

In order that light reflected by the detectors does not return to source, the input may be fitted with a circulator to allow the signals to continue to their destination or to be dumped or passed on for further measurement, e.g. to another circulator and another wavelength specific sensor of the type

described (but tuned to another wavelength). A cascade of such circulators and wavelength specific sensors may be provided to enable a plurality of wavelengths to be monitored.

The system could be designed to optimise reflection (i.e. rejection) of wavelengths or reflectivity of the grating could be lower. In this case, ideally all of the optical power carried by the wavelength $\lambda_1$ or wavelength range would be absorbed at the first photodetector, with the other wavelengths, $\lambda_1$, $\lambda_2$, ...., $\lambda_N$, being reflected. However, the arrangement could be designed so as to photoabsorb only a small fraction, say 1-5%, of the total optical power in the waveguide. This is a common requirement for optical monitoring of an optical network. In fact, the conventional OCM of Figure 5 would typically be employed in a network to monitor the spectral composition of the light output from a major network element such as an optical add-drop multiplexer (OADM) or an erbium-doped amplifier (EDFA) 40 (see Figure 7). In such an application, the conventional OCM 41 would be preceded by a tap coupler 42 before its input that would extract typically 1-10% of the total optical power from the main network connection for monitoring purposes, while allowing the remainder to propagate onwards in the network (as illustrated in Figure 7).

Where the reflectivity of the Bragg gratings is high (typically >0.99) then, effectively, the first Fabry-Perot cavity could monitor the combined power of a range of wavelengths, all other wavelengths being reflected. The light of the wavelength range monitored by the first sensor would be transmitted along the waveguide to the next Fabry-Perot cavity detector where a narrower range of wavelengths (or a specific wavelength) could be monitored.

An advantage of the arrangement of Figure 6 is that if the photodetectors are each designed only to absorb a small fraction of the total optical power (~1-10%) then the tap coupler 42 of Figure 7 is no longer required. Implementing such a small tap using evanescent couplers is difficult as the tap fraction and polarisation dependent losses thereof are difficult to control.

Further advantages of the arrangement of Figure 6 over the more conventional approach include the compact and monolithic nature of the device. In Figure 6 the power tap, wavelength separation and photodetection functions are combined into a single monolithic chip rather than being realised as separate elements. In contrast, in the conventional approach, the tap coupler may often be implemented using a fibre coupler, the wavelength separation may be a silicon AWG, e.g. formed on a silicon-on-insulator (SOI) chip, and the photodiode array may be a III-V semiconductor array that is hybridised onto the SOI chip using epoxy adhesive.

The AWG-based OCM shown in Figure 5 also typically occupies a large amount of space on the optical chip; a chip that is roughly 5x7cm would not be unusual. This is because of a number of contributing factors, including the length required for the free propagation regions 21, 23 of the AWG, the length of the AWG 22 itself and the space for the fan-out of the output waveguides 24 to the wide hybridised photodiode array 25.

In contrast, the arrangement of Figure 6 is based upon a single waveguide and so can be made very compact. The size limitations depend mainly upon the total length of the device and the minimum bend radius of the waveguide. The device length will depend upon, among other factors, the sensitivity of the individual photodetectors and the number of wavelengths (N) in the system while the minimum bend radius will depend upon the etch-depth of the photonics.

The arrangement shown in Figure 6 could be modified to take up a compact, snake-like layout such as that shown in Figure 8. In this layout, the detection elements $50_1$, $50_2$ ...... $50_n$ may be separated from each other by isolation features 51 of the type disclosed in PCT/GB01/04191, in particular n-i-p-i-n dopant isolation and etched trenches. These measures reduce both optical and electrical crosstalk between the photodetectors.

Other similar compact layouts can also be envisaged, e.g. running the waveguide on a spiral path or minimising the size further by positioning the monitor sections on the waveguide bends. If the detection element (gratings plus diode) is 10mm long and 250μm wide then, allowing for bends, a 40-channel OCM would occupy ~25x10mm, i.e. ~1/14 of the area of a conventional OCM. This opens up the possibility of integrating the OCM functionality onto the same optical chip as other photonic functions. For example, the configuration of Figure 8 could be fabricated on a single optical chip. This would greatly simplify fabrication, create a more compact device and reduce chip-to-fibre interface losses.

As mentioned earlier, when the full spectrum of light passes into the first detector element, which is set to sample the wavelength $\lambda_1$, the other wavelengths $\lambda_2$, ...., $\lambda_N$ may also undergo a single-pass of this first detector. As a result, they also contribute to the total photocurrent of this element. This is undesirable as it represents a crosstalk component of the photocurrent. The resonant detection of $\lambda_1$ will mean that, in most circumstances, the effect of the other wavelengths is relatively small but this is not always the case. A particularly bad case would be a DWDM system comprising a large number of channels, say many tens of channels, in which the $\lambda_1$ wavelength had a low optical power while all the other channels had high powers. This problem could be dealt with by signal processing electronics. For example, if $\lambda_1$ was a low power signal but $\lambda_2$ was a high power signal (thus giving significant crosstalk at the $\lambda_1$ detector), the large $\lambda_2$ power would be picked up at the $\lambda_2$ detector. The reading on the $\lambda_2$ detector could then be used to deduce the fraction of the photocurrent from the $\lambda_1$ detector that was a result of crosstalk from $\lambda_2$. This crosstalk could then be subtracted from the signal in digital signal processing (DSP) electronics to give a true reading of the power in $\lambda_1$. Likewise, the crosstalk from the other spectral components could be removed from the data.

Another potential problem, which does not arise in a conventional OCM, is that of saturation of the detectors. Consider again the $\lambda_1$ detector's behaviour. If the number of wavelengths in the system, N, is large and most DWDM channels are operating at their maximum optical power, then the total optical power through $\lambda_1$ will be very high. This opens up the possibility that the total power may be large enough to push the $\lambda_1$ detector towards the saturation region of its operation, particularly if the $\lambda_1$ signal is also large. The detector would therefore start operating in a non-linear region of its response curve and would thus give inaccurate power measurements. This would mean that the range of powers over which the OCM could be used would be reduced, i.e. the dynamic range of the device would be decreased. To avoid this difficulty, the photodetectors can be designed with photosensitivities appropriate to the anticipated powers that would be measured and to optimise the Fabry-Perot cavity design so as to make the wavelength-selectivity of the detectors as high as possible. The photosensivity of the detectors could be adjusted by altering the levels of the dopant, e.g. gold, used to absorb the light. For example, in a network where it was known that the signal $\lambda_2$ was always going to operate over a higher range of powers than $\lambda_1$ then the level of doping in the $\lambda_2$ detector could be reduced in comparison to the $\lambda_1$ detector, thus making it less responsive to the light incident upon it.

Another possibility for dealing with detectors with different dynamic ranges would be to introduce variable optical attenuators (VOAs) into the signal path. The VOAs would typically be absorption VOAs which would essentially consist of PIN diodes placed laterally across the waveguide with a length appropriate to the required attenuation and available chip space. A VOA will attenuate the light that is input into all of the wavelength-selective detectors that follow it and so the most likely location for a VOA is at the front on the detector series, before the $\lambda_1$ detector, where it would attenuate all the input light uniformly. A second possibility would be to have VOAs positioned between each wavelength dependent detector which would give some flexibility, such that the ordering of the wavelength detectors along the waveguide length would be

such that the most sensitive detectors would be placed farthest from the input. Thus, the light level would be progressively attenuated along the waveguide path as it passes into progressively more sensitive detectors. In this multiple-VOA configuration, the wavelength sensitivity of the VOAs could be exploited to enhance the wavelength selectivity of the detector. For example, PIN diode absorption VOAs that use the free carrier dispersion effect as the basis of their operation are more effective at attenuating longer wavelength signals. This means that there would be enhanced selection of shorter wavelength signals at the detectors placed at the downstream end of the series, so it would be preferable to place longer wavelength detectors closer to the input at the upstream end of the series. Of course, where the signal is expected to be propagated onwards in the network after the photodetector series (i.e. the application is a tap-monitor application rather than 100% detection) then it may be inappropriate to use VOAs.

A further extension of the above, would be to make the wavelength-selective detector or detectors dynamically tuneable. This may be done, for example, by using heater elements 60 placed adjacent to the Bragg gratings 61 and/or to the detector elements 62 as shown in Figure 9. The heaters 60 can be used to change the temperature of the silicon rib waveguide which means that its refractive index will also be altered via the thermo-optic effect. This can be used to change the wavelength selected by the detector.

A dynamically tuneable wavelength-selective detector would enable increased functionality over the suggestions already made above. It could, for example, be used as a single tap monitor that could be set to a wavelength chosen by the network management system. Another possibility is that it could be used to dynamically scan across a continuous spectral range for power monitoring purposes. This would allow the function of an OCM (described above) to be implemented in a compact device with the advantage that the entire wavelength spectrum could be sampled. As stated previously, one of the problems of the known OCM shown in Figure 4 is that the details of the

spectral content are lost because the optical power measured by the pixels of the photodiode 25 only record the power in the respective output waveguides 24. The output waveguides 24 effectively sample the power in the particular region of the spectrum that corresponds to the channel bandwidth, rather than the detailed spectral components that make up the total power found within that spectral regional. A scanned wavelength-selective detector would instead measure a continuum of wavelengths. This is particularly desirable for monitoring the power in high bit rate systems, say 40Gbps or greater, where OCMs suffer from intrinsic crosstalk due to the high bit rate leading to the spectral content of the signal spreading into adjacent channels.

Whilst Bragg gratings are preferred, other forms of wavelength selective reflectors may be used.

As described above, the reflector preferably reflects a single selected wavelength but in other cases it may be desirable to reflect a narrow band of selected wavelengths, to reflect a plurality of selected wavelengths or to reflect a broader band of selected wavelengths whilst rejecting wavelengths outside this band.

The p-i-n diode used to detect the charge carriers generated in the sensor may be arranged in other ways, e.g. laterally, vertically, longitudinally etc, so long as the p- and n- doped regions are positioned so that an electrical signal is generated across the diode in response to the generation of free charge carriers in the sensor. Other forms of detector means may also be used to detect the presence of the free charge carriers.

As described above, said portion of the light path preferably absorbs light of a selected wavelength to generate free charge carriers. This can be achieved in a variety of ways including the provision of one or more of the following in said portion: amorphous material, polycrystalline material, an alloy, a material which has been doped and/or had defects formed therein to provide deep

band gap states within the band gap thereof and a material having isolated regions, e.g. quantum dots, therein which generate charge carriers when illuminated by the selected wavelength. Alternatively, said portion of the path is provided with one or more metallised areas which form a Schottkey barrier with the material of said portion.

## CLAIMS

1. A light sensor comprising: a light conductive path, a portion of said path being arranged to generate free charge carriers when light of a selected wavelength or range of wavelengths passes along the path; wavelength selective reflector means being arranged to reflect light of said selected wavelength or range of wavelengths so it passes repeatedly through said portion; and detector means arranged to detect the presence of the free charge carriers thus generated.

2. A light sensor as claimed in claim 1 in which the reflective means comprises first and second reflectors.

3. A light sensor as claimed in claim 2 in which the first and second reflectors are provided in said light conductive path on opposite sides of said portion.

4. A light sensor as claimed in claim 2 or 3 in which at least one of the first and second reflectors comprises a Bragg grating.

5. A light sensor as claimed in any preceding claim which is tuneable so as to be sensitive to one or more selected wavelengths or wavelength bands.

6. A light sensor as claimed in claim 5 in which first wavelength control means are provided to adjust the wavelength or band of wavelengths reflected by the reflector means.

7. A light sensor as claimed in claim 5 or 6 in which second wavelength control means are provided to adjust the wavelength or band of wavelengths absorbed within said portion.

8. A light sensor as claimed in claim 5, 6 or 7 which can be scanned over a range of wavelengths to provide a spectral analysis of the light received.

9. A light sensor as claimed in any preceding claim comprising an optical attenuator for attenuating the light passing along said light conductive path.

10. A light sensor as claimed in claim 9 in which said attenuator is a variable optical attenuator.

11. A light sensor as claimed in any preceding claim in which said light conductive path comprises a rib waveguide.

12. A light sensor as claimed in claim 11 in which the rib waveguide is a silicon rib waveguide.

13. A light sensor as claimed in any preceding claim in which said portion of said path comprises one or more regions of light absorbing material.

14. A light sensor as claimed in claim 13 in which the light absorbing material comprises one or more of the following: amorphous material, polycrystalline material, an alloy and a material which has been doped and/or had defects formed therein to provide deep band gap states within the band gap thereof.

15. A light sensor as claimed in any of claims 1-12 in which said portion of said path comprises one or more metallised areas which form a Schottkey barrier with the material of the path.

16. A light sensor as claimed in any preceding claim in which said detector means comprises a diode.

17. A light sensor as claimed in claim 16 in which said portion is nominally intrinsic and p- and n-doped regions are formed adjacent said intrinsic region to form a p-i-n diode.

18. A light sensor as claimed in any preceding claim arranged to absorb only a small fraction, preferable 10% or less, of the light of said selected wavelength received thereby.

19. A light sensor as claimed in any of claims 1-17 arranged to absorb substantially all of the light of said selected wavelength received thereby.

20. A light sensor substantially as hereinbefore described with reference to and/or as shown in one of more of Figures 1 to 4 and 9 of the accompanying drawings.

21. Two or more light sensors as claimed in any preceding claimarranged in series or in parallel.

22. Two or more light sensors as claimed in claim 21 in which each sensor is arranged to be sensitive to a different wavelength or wavelength band.

23. Two or more light sensors as claimed in claim 21 or 22 arranged in series along a substantially straight light conductive path.

24. Two or more light sensors as claimed in claim 21 or 22 arranged in series along a serpentine light conductive path.

25. Two or more light sensors as claimed in claim 24 formed on a substrate, said substrate having optical and/or electrical isolation

devices formed therein positioned so as to assist in optically and/or electrically isolating different portions of said serpentine path from each other.

26. Two or more light sensors as claimed in any of claims 21-25 each having a variable optical attenuator in series therewith.

27. Two or more light sensors as claimed in any of claims 21-26 arranged to form an optical channel monitor for monitoring the individual channels of a multi-wavelength optical signal.

28. Two or more light sensors substantially as hereinbefore described with reference to and/or as shown in one or more of Figures 6 and 8 of the accompanying drawings.

29. A photodiode comprising a p-i-n diode formed in a semiconductor substrate having an energy band gap the magnitude of which corresponds to absorption of photons of a first wavelength, the photodiode comprising a substantially intrinsic region in said semiconductor substrate between p- and n-doped regions, the intrinsic region being modified to introduce deep band gap levels therein so as to provide at least partial absorption of photons of an optical signal of a selected wavelength or wavelength band greater than said first wavelength and thus generate an electrical signal across the p-i-n diode indicative of said optical signal, said photodiode being provided within a resonant cavity.

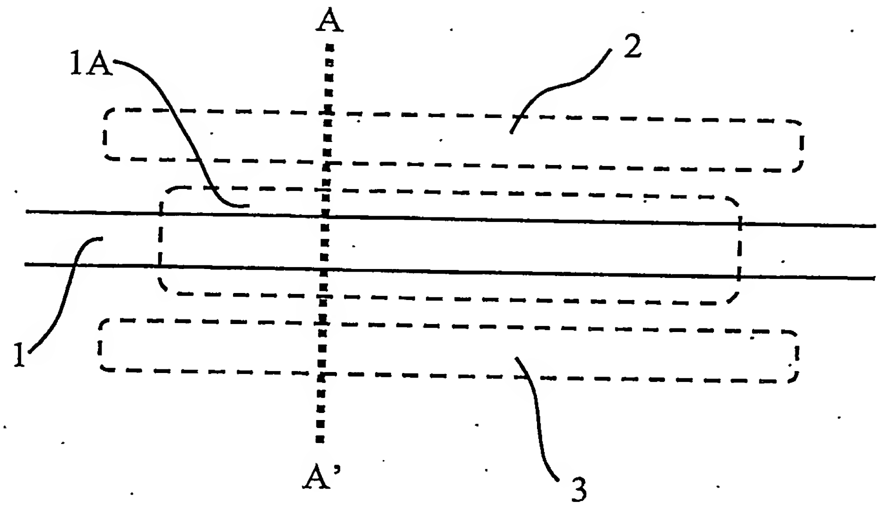


Figure 1

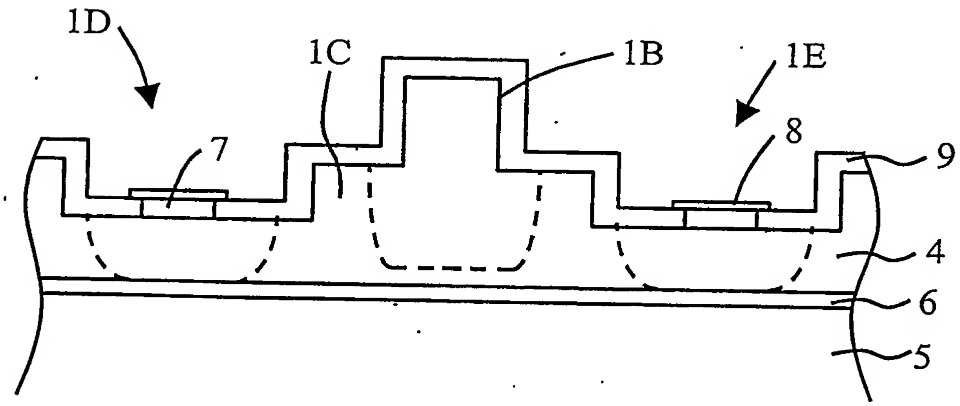


Figure 2

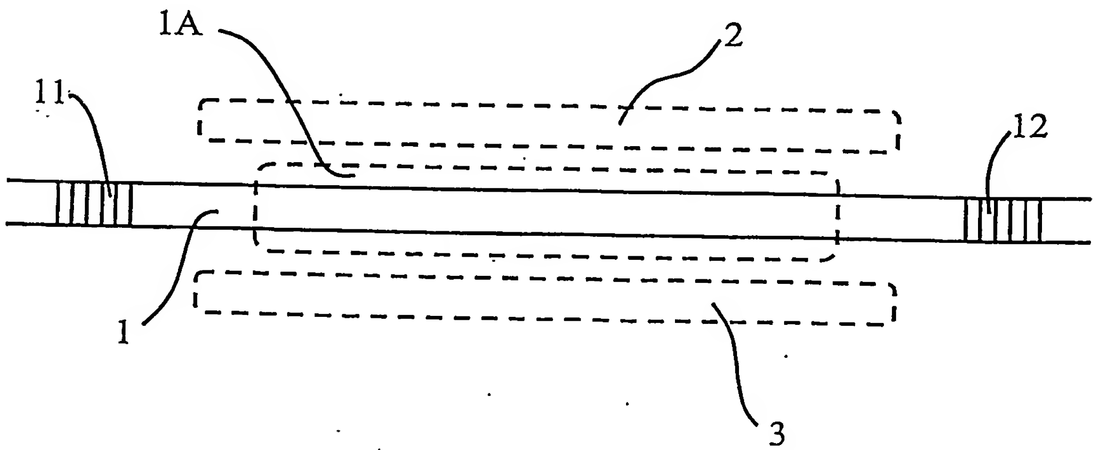


Figure 3

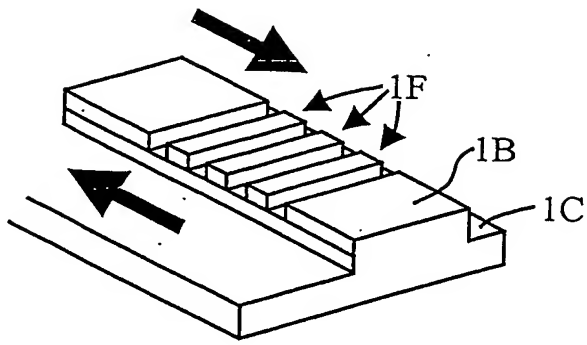


Figure 4

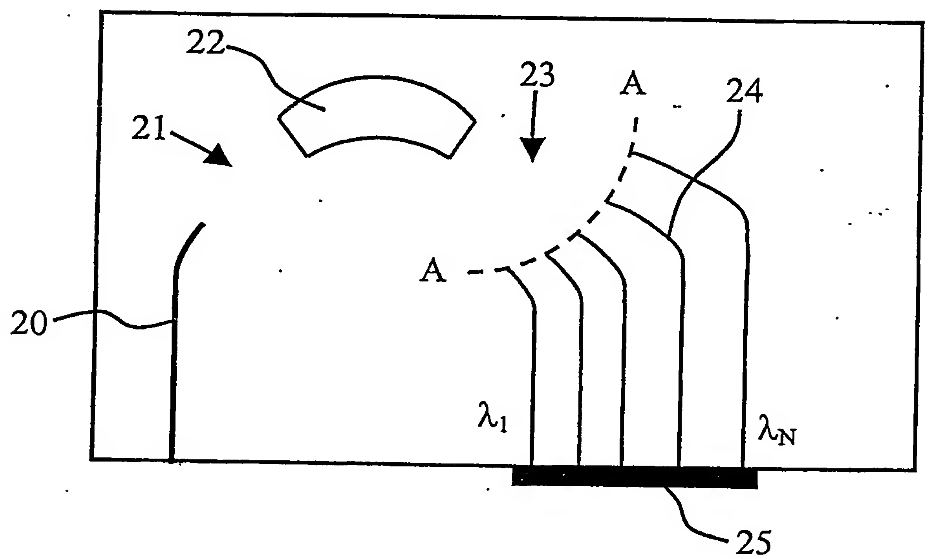


Figure 5

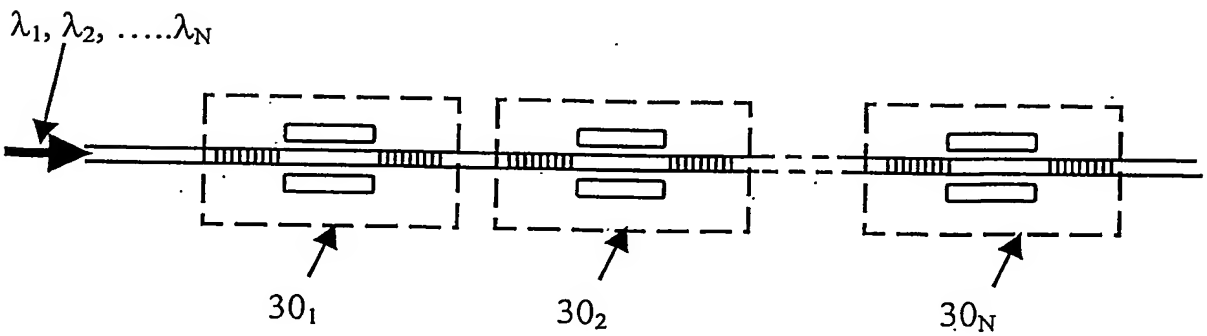


Figure 6

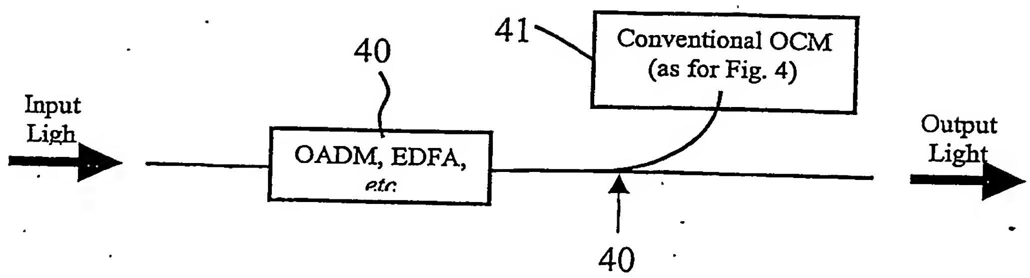


Figure 7

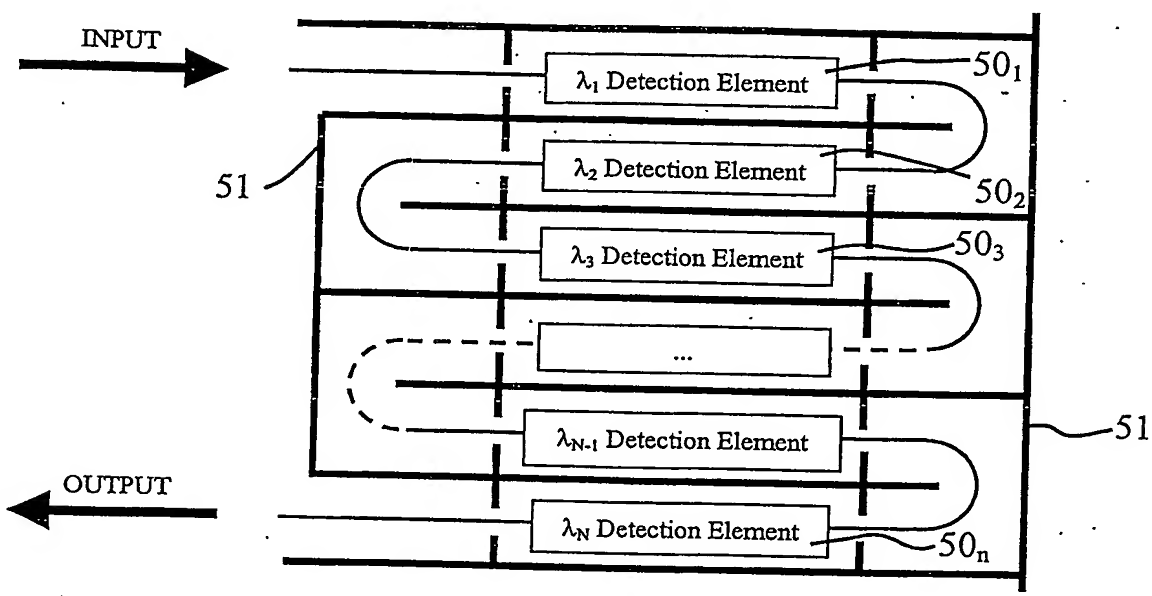


Figure 8

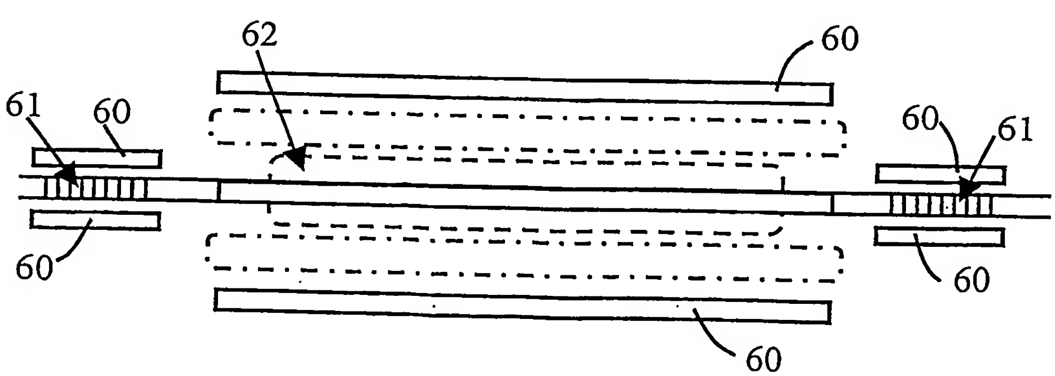


Figure 9